LOW ENERGY γ-RAY EMISSION FROM THE CYGNUS OB2 ASSOCIATION

Wan Chen[1,2] and Richard L. White[1]

[1]Space Telescope Science Institute
3700 San Martin Drive, Baltimore, MD 21218

[2]Department of Physics and Astronomy
The Johns Hopkins University, Baltimore, MD 21218

ABSTRACT

According to our newly developed model of γ-ray emission from chaotic early-type stellar winds, we predict the combined γ-ray flux from the circumstellar winds of many very luminous early-type stars in the Cyg OB2 association can be detectable by EGRET (and maybe also by OSSE) on *CGRO*. Due to different radiation mechanisms, the γ-ray spectrum from stellar winds can be quite different from that of Cyg X-3; this spectral difference and the time-variation of Cyg X-3 flux will help to distinguish the γ-ray components from different sources in this small region, which is spatially unresolvable by *CGRO*.

1. OVERVIEW

The region of the Cyg OB2 association is of interest to γ-ray astronomy because it contains one of the most important and mysterious Galactic γ-ray sources, Cyg X-3, which has been detected in keV, TeV and even PeV energies (see Bonnet-Bidaud & Chardin (1988) for a critical review of Cyg X-3 observations and theories). Surprisingly enough, however, Cyg X-3 was not detected in $0.7 - 5$ GeV range by *COS B*, in conflict with earlier *SAS II* results. It has long been expected that observations by EGRET onboard *CGRO* will help to clarify this situation.

We suggest here that there may be some new confusion. As we discussed earlier (Chen & White, this volume), γ-rays can be produced by the circumstellar winds of early-type stars. The dense Cyg OB2 association, harboring the hottest and most luminous massive stars known in the Galaxy, may be a particularly interesting γ-ray source competing with Cyg X-3 at EGRET energies. Another complication is that the diffuse γ-ray background in the Cygnus region is among the highest on the Galactic plane (Mayer-Hasselwander *et al.* 1987). It may severely reduce the sensitivity of detecting weak point sources for γ-ray telescopes with moderate spatial resolution like EGRET.

2. WHAT'S KNOWN?

Cyg X-3 has been well measured at hard X-ray energies. It has a steep photon spectrum from 20 keV to 140 keV (Hermsen *et al.* 1987),

$$\frac{dN}{dE} = (40.3^{+17.6}_{-10.1}) E_{keV}^{-(3.19^{+0.11}_{-0.07})} \text{ photon cm}^{-2} \text{ s}^{-1} \text{ keV}^{-1}. \tag{1}$$

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Above 140 keV, the situation is not clear (Bonnet-Bidaud & Chardin 1988). At very high energies (VHE) and ultra-high energies (UHE), Cyg X-3 has been a popular target in the last twenty years and many detections have been reported (Chardin & Gerbier 1989), though the statistics for the detections are usually rather poor. The reported photon spectrum from 10^{11} eV to 10^{17} eV can be best represented by a pure power-law (Rana et al. 1984),

$$\frac{dN}{dE} = 2.7 \times 10^{-4} \, E_{keV}^{-1.78} \, \text{photon} \, \text{cm}^{-2} \, \text{s}^{-1} \, \text{keV}^{-1}. \tag{2}$$

The γ-ray flux of Cyg X-3 at GeV energies is quite controversial (Bonnet-Bidaud & Chardin 1988). The *SAS II* observations reported detection of Cyg X-3 with a flux of $\sim 1.1 \times 10^{-5} \, \text{photon} \, \text{cm}^{-2} \, \text{s}^{-1}$ above 35 MeV (Lamb et al. 1977). Subsequent observations by *COS B* for a total of ~ 300 days, however, did not detect Cyg X-3. The *COS B* upper limit is about an order of magnitude below the *SAS II* flux but it is consistent with the extrapolation of the UHE power-law spectrum (equation 2) down to GeV energies (Hermsen et al. 1987).

The distribution of the diffuse γ-ray background on the Galactic plane is very lumpy (Mayer-Hasselwander et al. 1987). The Galactic center region has the strongest diffuse emission. There is also a peak in the background in the Cygnus region, with an average flux about a factor of two below the Galactic center value. The diffuse γ-ray emission in the Cygnus region has extensive structure which does not always follow the gas distribution derived from H I and CO observations of the region (Hermsen et al. 1987). Cyg X-3 is located just outside the local maximum in the background and is also a few degrees away from three unidentified point sources detected by *COS B*.

Table 1. Massive stars in Cyg OB2 (1.7 kpc) near Cyg X-3 (8.4 kpc)

Name	Sp	l^{II}	b^{II}	$\delta\theta_{X-3}{}^a$	$L_{bol,40}{}^b$	$M_{-5}{}^c$	$V_{\infty,3}{}^d$	$R_*{}^e$
Cyg X-3	79.90	0.70						
Cyg OB2								
No. 22	O4 IIIf	80.14	0.75	$14'.7$				
No. 9	O5 If	80.17	0.76	$16'.6$	1.57	1.9	2.6	34
No. 5	O6 If†	80.10	0.90	$17'.0$	1.04	2.5	2.2	34
No. 18	B1 Ib	80.21	0.71	$18'.6$				
No. 8A	O6 Ibf	80.22	0.79	$20'.0$	0.77	3.2	3.2	30
No. 8B	O6.5 IIIf	80.22	0.79	$20'.0$				
No. 8C	O5 IIIf	80.23	0.78	$20'.4$				
No. 7	O3 If	80.24	0.80	$21'.3$	0.97	1.9	2.7	20
No. 19	O9.5 III	80.28	0.73	$22'.9$				
No. 16	O7.5 V	80.24	0.94	$25'.0$				
No. 15	O8 V	80.24	0.98	$26'.4$				
No. 4	O5 IIIf	80.22	1.02	$27'.2$				

† Binary, only parameters for the primary are listed; ^{a} Angular distance from Cyg X-3; ^{b} Stellar bolometric luminosity in $10^{40} \, \text{ergs} \, \text{s}^{-1}$; ^{c} Stellar mass loss rate in $10^{-5} \, M_\odot \, \text{yr}^{-1}$; ^{d} Wind terminal velocity in $10^3 \, \text{km} \, \text{s}^{-1}$; ^{e} Stellar radius in $R_\odot$; Ref. Massey & Thompson (1991) and Bieging, Abbott & Churchwell (1989).

Less than 1° northeast of Cyg X-3, there is the classical "cluster of blue giants", the Cyg OB2 association, which contains a large number of massive OB stars (Massey & Thompson 1991). In fact, a dozen of the brightest and most massive stars known in the region are located within 30' of Cyg X-3 (Table 1). (This is also roughly the angular size of the point-spread-function (PSF) of EGRET at $E > 0.5$ GeV.) Though it is believed that there is large amount of interstellar gas in the Cyg OB2 region, there is no significant diffuse γ-ray enhancement seen in the COS B contour map (Hermsen et al. 1987).

3. WHAT'S EXPECTED?

We expect that substantial γ-ray radiation can be produced in the massive circumstellar winds of early-type stars (see Chen & White, this volume and references therein). The stellar wind γ-rays have two origins: the electron-generated inverse Compton quasi-power-law component extending from keV to > 10 MeV energies, and the ion-produced π^0-decay γ-ray hump peaking at ~ 67 MeV. The most luminous stars should have large inverse Compton luminosities, and the most massive winds may produce large π^0-decay γ-ray luminosities. Usually the most luminous stars also have the most massive winds because the winds of O stars are believed to be radiatively driven (Castor, Abbott & Klein 1975). Since we do not have the stellar and wind parameters for all the stars in Table 1, we calculated the expected γ-ray fluxes from only 4 stars, Cyg OB2 No. 5, No. 7, No. 8A and No. 9, for which we have good data (Table 1).

Figure 1 shows our prediction of the γ-ray emission from the Cyg X-3/Cyg OB2 region in the CGRO energy range. The dot-dashed lines marked OB2 are the accumulated γ-ray fluxes from the four stars in Cyg OB2 association. We expect the real total flux, including all the stars in the association, will be less than a factor of 2 greater than the flux shown here since the included stars are also the brightest and have the most massive winds in the group.

Also shown in Figure 1 with the dotted lines are the 3σ point source continuum sensitivities[1] for OSSE, COMPTEL and EGRET during a normal two-week on-axis observations.

The solid line marked X3 is the observed hard X-ray spectrum of Cyg X-3 (Hermsen et al. 1987), and the dashed line is a power-law extrapolation. Also marked X3 and shown with a dashed line in the EGRET range is the power-law extrapolation of the Cyg X-3 spectrum at VHE and UHE (equation 2; Rana et al. 1984).

The solid line marked GB is the diffuse γ-ray background spectrum of the Galactic center region (Fichtel & Kniffen 1984), divided by a factor of 2 and convolved with the energy dependent PSF[1] of EGRET and COMPTEL. It increases sharply at low energies because of the decreasing spatial resolution of both EGRET and COMTEL at low energies.

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[1]From Appendix G of NRA 91-OSSA-22: The Gamma Ray Observatory as a Guest Investigator Facility, (NASA/GSFC:Greenbelt)
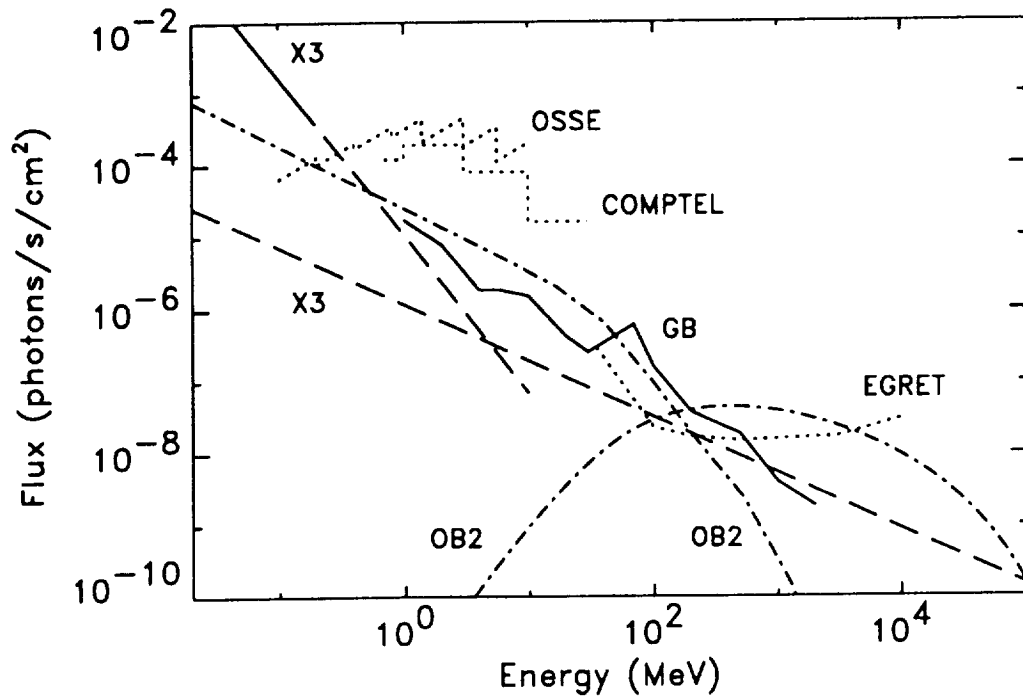
Figure 1. γ-ray spectra in the Cyg X-3/Cyg OB2 region. The solid lines are observed spectra, the dashed and dot-dashed lines are predicted spectra, and the dotted lines are instrument sensitivity curves. As marked X3 stands for Cyg X-3; OB2 for Cyg OB2; GB for the Galactic diffuse background.

3. WHAT CAN BE DONE?

We see that the chances of detecting Cyg X-3 with OSSE are very good, since we can reasonably expect the hard X-ray spectrum of Cyg X-3 will extend to at least a few hundred keV. The Cyg OB2 flux in the OSSE range is confined to the low-energy end, where it is completely dominated by the flux from Cyg X-3 with a much steeper spectrum. At COMPTEL energies neither Cyg X-3 nor Cyg OB2 can be detected.

The Cyg OB2 flux becomes dominant at the high energy end of EGRET where the fluxes of both Cyg X-3 and the diffuse background are low. However, from a recently developed theory on high energy emission from accreting X-ray pulsars (Cheng *et al.* 1991), the potential γ-ray flux from Cyg X-3 at EGRET energies could be about an order of magnitude higher than we have shown here. If this is the case, Cyg X-3 could have a similar flux to Cyg OB2.

At the lower energy range of EGRET, the competition is between Cyg OB2 and the diffuse background. We see that both sources have similar spectra in this energy range, so it will be fairly difficult to distinguish them.

If Cyg X-3 has a much greater flux (Cheng *et al.* 1991), it may become a major competitor over the whole energy range of EGRET; this could probably be recognized through

its characteristic 4.8 hr time modulation (Bonnet-Bidaud & Chardin 1988). This time variation is observed in almost all the energy bands where Cyg X-3 has been detected (Bonnet-Bidaud & Chardin 1988). We may expect the emission at EGRET energies also to be modulated.

We conclude from the above analysis that observations of the Cyg X-3/Cyg OB2 region can be very fruitful. The diffuse γ-ray background in the region makes it much more difficult to detect and distinguish Cyg X-3 and Cyg OB2 at the spatial resolution of the present instrument. The most promising energy band for detection of the Cyg OB2 association is at the high energy end of the EGRET range. If Cyg X-3 has much larger flux than we have shown here, the 4.8 hr time variation will be the most likely criterion to reveal the true identity of the γ-ray source.

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